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METHODS AND COSTS OF MILLING FERBERITE ORE AT THE WOLF TONGUE CONCENTRATOR, NEDERLAND, BOULDER COUNTY, COLO.

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METHODS AND COSTS OF MILLING FERBERITE ORE AT THE WOLF TONGUE CONCENTRATOR, NEDERLAND, BOULDER COUNTY, COLO.[1]

By William O. Vanderburg[2]

INTRODUCTION

This paper describing the practice at the Wolf Tongue concentrator at Nederland, Colo., is one of a series on similar subjects being published by the United States Bureau of Mines.

The author acknowledges the assistance of William Loach, manager of the Wolf Tongue Mining Co., and of W. G. Roseborough, superintendent of the Wolf Tongue mill, in the preparation of this paper.

GENERAL DESCRIPTION

The Wolf Tongue concentrator occupies a hillside site on Middle Boulder Creek at Nederland, Colo. Nederland is 17 miles by automobile road southwest of Boulder, and its altitude is 8,220 feet above sea level. The concentrator has a maximum capacity of 1 ton of ore per hour when treating ferberite ores containing about 4 per cent of tungsten trioxide (WO_3). With higher-grade ores the capacity is less and may be as low as 1,000 pounds of ore per hour when treating ores containing over 10 per cent of tungsten trioxide.

The present mill was erected in 1928 to replace one that was destroyed by fire in the summer of 1927. The roof and sides of the mill building are of sheet asbestos placed on a timber framework; the foundation and floor are of concrete. The inside walls are gunited to afford protection against fire, to improve lighting, and for insulation against winter weather. The mill building is heated by two coal-fired hot-air furnaces.

The total cost of the mill fully equipped was $85,000. Of the total cost $60,000 was the contract price for the building and new machinery and the balance was for the reconditioning and setting of the older equipment, which went through the fire.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6685."

2 Associate mining engineer, U. S. Bureau of Mines.

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Of the total ore treated in 1931, 90 per cent was derived from the company owned and operated Cold Springs mine; the remaining 10 per cent was custom ore purchased from lessees. At the Cold Springs mine the cut-and-fill system of mining is employed in conjunction with selective mining, hand sorting, and cobbing. About 85 per cent of the material broken in mining is rejected as waste before milling.

The company owns a water right on Middle Boulder Creek from which power for milling purposes is generated. The power plant is adjacent to the mill and is equipped with a Leffel wheel direct-connected to a 100-kv. a. generator. The head gate and earth dam are 2,700 feet distant from the power plant, and water under a total head of 100 feet is delivered to the latter through a 4 foot diameter Oregon-fir pipe line. Water for milling is obtained also from this pipe line by gravity flow, and as plenty of water is available there is no necessity for reclaiming the used mill water.

ORES TREATED

The only economic mineral in the ores treated is ferberite, the tungstate of iron ($FeWO_4$). Ferberite is one of the wolframite series of minerals and when pure has a composition of 23.7 per cent of ferrous oxide (FeO) and 76.3 per cent of tungsten trioxide (WO_3). The ore treated at the Wolf Tongue mill in 1931 contained an average of 5.72 per cent of tungsten trioxide.

Most of the ferberite ores in the Boulder district are relatively free from associated gangue minerals with the exception of quartz. The quartz occurs in the ferberite veins in much less amounts than is ordinarily present in the quartz-type of veins. According to Hess,[3] associated minerals other than quartz are few and scarce. Adularia, calcite, chalcedony, chalcopyrite, galena, gold, silver, limonite, magnetite, opal, pyrite, scheelite, sphalerite, and sylvanite may be present - however, locally and in very small amounts.

From a marketing viewpoint the only objectionable impurity occurring in the Boulder district ferberite ores and concentrates is phosphorus. The percentage of phosphorus, however, can be kept below the limit demanded by the consumers of tungsten concentrates.

The ores treated at the Wolf Tongue concentrator may be classified into two general types: (1) Ores wherein the ferberite is liberated from the gangue by coarse crushing, and (2) ores of the "hornstone" or chalcedonic type wherein the ferberite and quartz comprise a cryptocrystalline aggregate that requires fine grinding to liberate the ferberite.

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3 Hess, Frank L., and Schaller, Waldemar T., Colorado Ferberite and the Wolframite Series: U. S. Geol. Survey Bull. 583, 1914, pp. 12-17.

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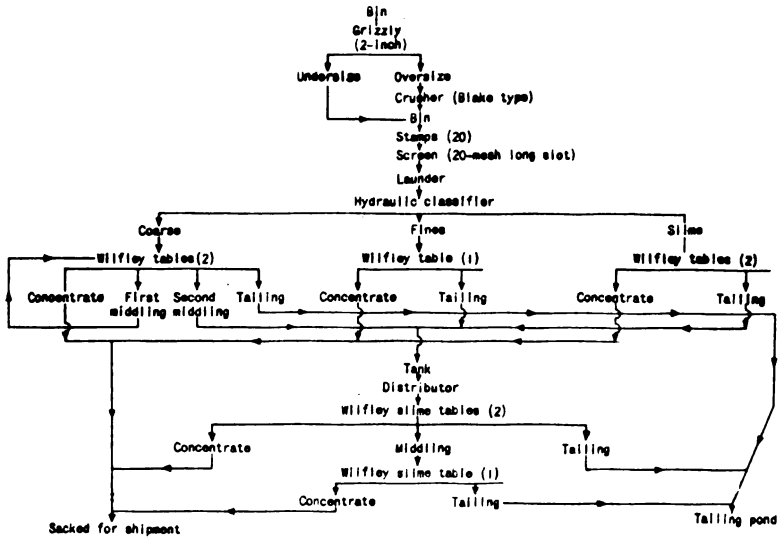

Figure 1.- Wolf Tongue concentrator flow sheet, 1905

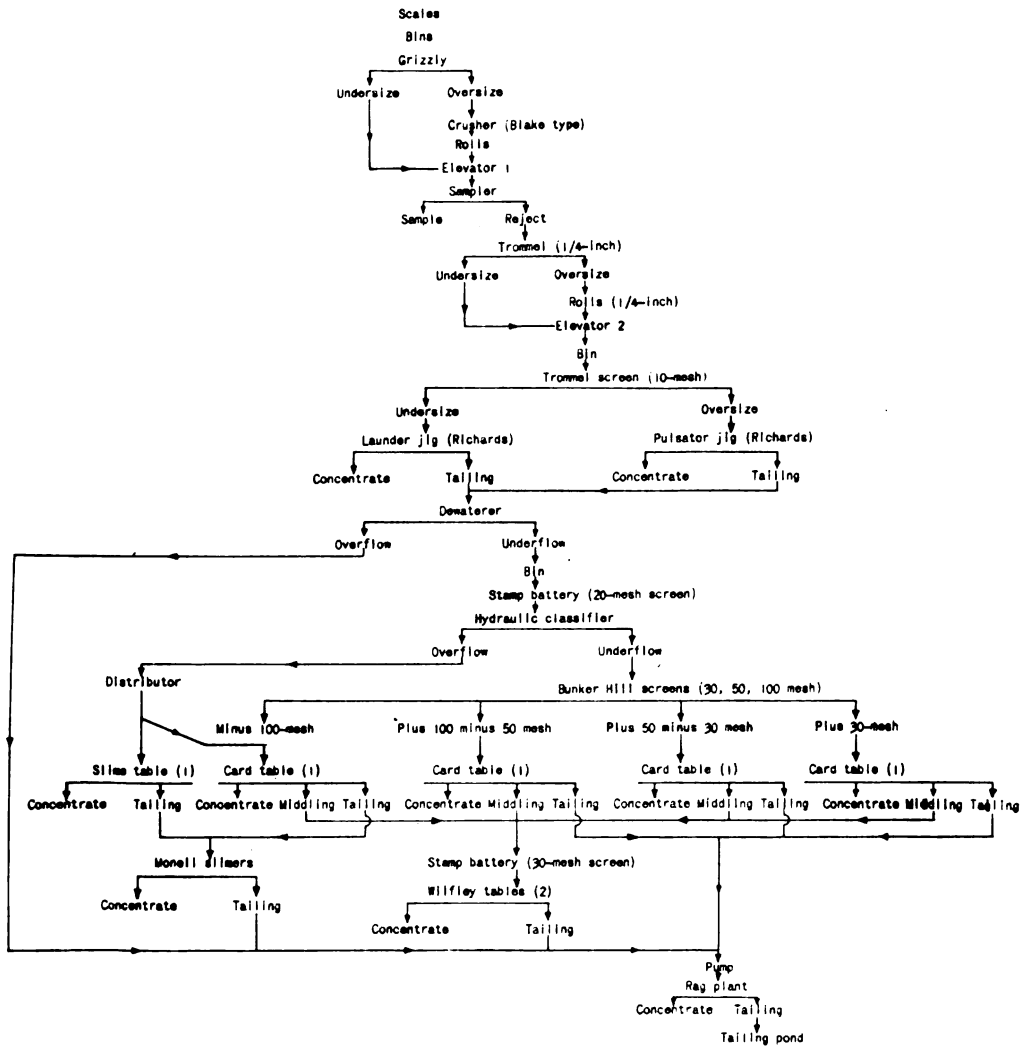

Figure 2.- Wolf Tongue concentrator flow sheet, 1917

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Because of the extreme friability of the ferberite an excessive amount of slimes is produced in crushing, especially when fine grinding is used, which makes concentration by gravity methods difficult and renders uneconomical under present conditions the treatment of ores containing less than 3 per cent of WO_3. Although the specific gravity of ferberite is 7.5 and that of the gangue about 2.7, no equipment yet devised has been wholly effective in recovering slimed ferberite as a high-grade concentrate. In milling the ores it is necessary therefore to compromise between the recovery made and the grade of the concentrate produced, as a high-grade product results in a lower recovery and a high recovery results in a portion of the concentrate being of too low grade to be readily marketed.

With ores containing from $3\frac{1}{2}$ to 30 per cent of WO_3 recoveries have averaged about 90 per cent; the maximum recovery over a 1-year period was 92 per cent. A milling recovery of 90 per cent is exceptionally high for any of the economic tungsten ores with the present methods of gravity concentration, but it should be understood that a part of the concentrate produced when such recovery is made is a low-grade product that can be sold only at a very large discount from the price quoted for concentrates containing 60 per cent of WO_3 or better. As an illustration, the average recovery of WO_3 at the Wolf Tongue concentrator in 1931 was 86.6 per cent; 70.3 per cent of the total WO_3 in the ore milled was recovered in a high-grade concentrate containing 54.38 per cent of WO_3 and the remaining 16.3 per cent in a low-grade concentrate containing 31.73 per cent of WO_3.

BRIEF HISTORY OF CONCENTRATOR OPERATIONS

The first concentrators for treating tungsten ores in the Boulder district were erected about 1903. In comparison with the results of present practice the early mills were not very efficient, due largely to the fact that the characteristics of ferberite ores were not thoroughly known. Before the Boulder field became prominent as a producer of tungsten ore Nederland had been the center for gold and silver mining operations in adjoining areas. The old mills that formerly treated the gold and silver ores were subsequently converted to tungsten concentrators, and the flow sheets established for milling the gold and silver ores were retained for treating tungsten ores, with unsatisfactory results.

The first Wolf Tongue concentrator to treat tungsten ore was equipped with gravity stamps. The flow sheet used at this mill in 1905 is given in Figure 1.[4] This mill had a capacity of 50 tons per 24 hours, and a recovery of 60 per cent of the WO_3 was considered good work. Concentration ratio was 15 into 1.

4 Van Wagenen, H. R., Tungsten in Colorado: Frenzel Prize Thesis, Colorado School of Mines, 1905.

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Compared with the more elaborate flow sheets later developed the treatment of the ore in 1905 was very simple. The main defect in the milling methods practiced in the early mills was fine crushing by stamps at too early a stage, which resulted in the loss of much tungsten in the slimes.

The flow sheet of the Wolf Tongue concentrator as operated in 1917 is shown in Figure 2.[5] Improvements in practice of 1917 as compared to 1905 consisted in the substitution of the jaw crusher and rolls for stamps in crushing, the installation of jigs for the separation of coarse concentrate, the use of stamps for final crushing and grinding, the more thorough preparation of feeds to tables by screens and classifiers, and the installations of Monell slimers and a "rag plant" for the recovery of the slimed ferberite.

In the Wolf Tongue flow sheet as of 1917, emphasis was placed on the treatment of slime. The Monell slimers were subsequently found to be unsatisfactory for the milling of ferberite ores, because the very fine slime caked on the Monell slimer, yielding a low recovery.

The "rag plant" in 1917 consisted of 72 stationary canvas-covered tables each 5 feet wide and 20 feet long, with a total area of 7,200 square feet. To economize on space the 72 tables were arranged in three tiers placed vertically, there being 24 tables in each tier. The pulp was distributed to the upper tier of tables, from whence it flowed to the bottom tier of tables so that the slimes passed over 60 linear feet of canvas. At the lower end of each tier of tables was a continuous trough in which the concentrates were collected. At intervals, the pulp flow was stopped and the concentrates that had collected on the tables were washed with a stream of water into the troughs, which were connected by pipes to a concrete settling tank. The concentrates were collected after settling. The average grade of the "rag table" concentrate was about 30 per cent of WO_3. During the "boom" tungsten market that prevailed during the World War concentrates containing 30 per cent of WO_3 could be sold readily, so that the production of a high-grade concentrate was not so essential in 1917 as it is to-day.

In 1917, when the grade of ore treated was 10 per cent of WO_3, concentrator capacity amounted to 45 tons per 24 hours, and recovery at this time for the grade of ore noted was about 80 per cent.

PRESENT METHOD OF CONCENTRATING

The mill flow sheet used at present is shown in Figure 3. The method of treatment may be briefly summarized as follows:

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5 Fischer, S., jr., Modern Concentration of Colorado Tungsten Ores: Met. and Chem. Eng., vol. 16, 1917, pp. 559-562.

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1. Rough concentration is done at the mine by selective mining, hand sorting, and cobbing.

2. Crushing to minus $\frac{1}{4}$-inch is accomplished by two jaw crushers and one set of rolls.

3. The minus $\frac{1}{4}$-inch material is sized by screens into three products for jig treatment.

4. The coarse jig tailing, plus 1/8-inch, is crushed to 1/8-inch and returned to the jig; the minus 1/8-inch jig tailing is classified into 4 products, which are treated by a jig and sand tables.

5. Middlings from the sand tables and tailing from the jig are ground in a ball mill and returned to the sand tables for additional treatment.

6. Table tailing pulps are thickened and treated on six slime tables.

Two classes of concentrates are produced in the jigs and on the tables; the first grade contains about 55 per cent of WO_3 and the second grade from 30 to 35 per cent of WO_3.

Present practice in concentrating at the Wolf Tongue mill is characterized by the large amount of concentrating equipment required to treat a comparatively small tonnage of ore, and by the meticulous attention given the concentrating equipment by the mill operators. It has been found in treating tungsten ores of the Boulder district that it is impossible to crowd the mill without causing a decided reduction in recovery.

It may be noted that stamps are not used at present, as it is generally conceded by millmen in the Boulder district that stamps are unsatisfactory as crushers for the type of ore treated because they produce too large a percentage of slime. The basis for the objection to the use of stamps in tungsten milling is found in the physical properties of the ferberite; the heavy, friable ferberite, settles back on the mortar blocks and is ground finer than necessary, producing slime, which causes high tailing losses, as previously noted.

The "rag plant" in the present flow sheet is not primarily a part of the concentrating equipment; the three canvas tables are used as pilot machines to determine whether or not the sand tables are making satisfactory savings.

CRUSHING AND SCREENING

Ore mined by the company or by lessees is brought to the mill by automobile. Hauling is done on contract at a fixed rate of $1 per ton within a radius of 3 miles from the mill.

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Referring to Figure 3, the ore is first weighed on a Howe platform scale and then dumped from the truck into the crude-ore bins. From the crude-ore bins it passes over an inclined bar grizzly with ¼-inch openings. The grizzly oversize is crushed to ¾-inch size by a 7 by 10 inch Blake-type smooth-jaw crusher, equipped with manganese-steel wearing plates. The crusher discharge, along with the grizzly undersize, passes by gravity to a belt and bucket elevator that discharges into a woven-wire trommel screen with ½-inch openings. This trommel is 3 feet in diameter and 6½ feet long; it is set at a slope of 2 inches per foot and revolves at a speed of 15 r.p.m.

The trommel oversize is crushed to ½-inch size by a set of 16 by 36 inch McFarlane rolls equipped with chrome steel shells and operated in closed circuit with the trommel.

When concentrating ores averaging about 5 per cent of WO_3, the crushing equipment is operated about one-third of the mill running time.

The trommel undersize is sampled by a Vezin sampler, which takes an 8 per cent cut. The sampler reject passes by gravity into one of three storage bins, as each lot of custom ore is kept separate until settlement is made. From the storage bins the ore is distributed to the mill feed bin by a 16-inch belt conveyor equipped with a wooden plow set by hand, which discharges the ore from the belt into the bin.

The flow of ore from the mill feed bin onto a steel pan feeder is controlled by three rack-and-pinion gates. The apron feeder discharges into a trommel screen with ¼-inch openings. The plus ¼-inch product is further crushed to about ¼-inch in a No. 3 Universal jaw crusher equipped with smooth manganese-steel wearing plates. The crusher discharge and the trommel undersize pass by gravity to a second belt-and-bucket elevator, which discharges into two trommel screens, arranged in series, with ¼ and 1/8 inch openings, respectively. Water is used with these screens and the three sized products comprise the feeds for jigging operations.

JIGGING

The plus ¼-inch screen product is fed to a 1-compartment bull jig; the minus ¼ plus 1/8 inch material is handled by a 2-compartment jig; and the minus 1/8-inch product after dewatering is handled by a 3-compartment jig. All jigs are of the Harz type and have screen compartments 16⅔ by 30 inches in size. In the multiple-compartment jigs the drop between successive screens is 1 inch. Operating details of jigs are given in the table that follows:

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Operating details of jigs.

Size of feed ..... inches	Plus 1/4	Minus 1/4 plus 1/8	Minus 1/8
Number of compartments ...	1	2	3
Size of compartments ..... inches	30 by 16½	30 by 16½	30 by 16½
Screen area, total ..... square inches	495	990	1,485
Screen openings, size	3/8-inch	6-mesh	10-mesh
Depth of bed ..... inches	5½	4⅓	4½
Length of plunger stroke.. do.	¾	⅓	⅜
Plunger speed per minute.. strokes	250	250	250

The jig product is of two grades; one contains from 50 to 60 per cent of WO_3 and the other from 30 to 40 per cent of WO_3. Concentrates are removed from the jig beds at intervals by hand skimming, and at the end of each shift a general clean-up is made on all jigs.

Tailings from the coarse and medium jigs are dewatered and further crushed to about 1/8-inch size by one set of 14 by 27 inch rolls equipped with chrome-steel shells. The roll product is returned to the trommels ahead of the jigs. Tailings from the fine jigs are dewatered in an Akins classifier 3 feet in diameter by 12 feet long set at a slope of 2 inches per foot. The thickened product is sized for fine jigging and table treatments, and the classifier overflow is fed to a Dorr thickener placed at the head of the slime section.

The advantage in the use of jigs is that the concentrate is recovered in a coarse form; therefore they increase recovery and reduce the amount of equipment necessary for the treatment of the slimes.

FINE JIGGING AND TABLE TREATMENTS

The three screens for sizing fine jig and table feeds are 20, 40, and 80 mesh, respectively.

The plus 20-mesh material is treated by one Harz-type jig having a screen surface of 14 by 6 inches. The screen cloth is 6 mesh and the depth of bed is 5½ inches. The fine jig produces a hutch concentrate which contains from 50 to 60 per cent of WO_3, and a tailing which is ground and retreated by tables.

The minus 20 plus 40 mesh and the minus 40 plus 80 mesh screen products are each treated by a Wilfley table, and the minus 80-mesh material after thickening is also treated by a Wilfley table.

Each table makes four products--namely, first and second grade concentrates which contain from 50 to 70 and from 30 to 40 per cent of WO_3, respectively; middling, which is reground and retreated; and tailing, which is thickened in a Dorr thickener before retreatment in the slime plant unless the grade of ore being treated is low, in which case table tailings can be diverted to the tailings pond without further treatment.

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GRINDING OF FINE JIG TAILING AND TABLE MIDDLINGS

The fine jig-tailing and the sand-table middlings are thickened in a second Akins classifier. The classifier overflow is sent to the Dorr thickener at the head of the slime section and the thickened pulp is ground in a small-sized Marcy ball mill. The mill operates at a speed of 36 r.p.m., and a ball load of about 1 ton of balls ranging from 1 to 4 inches in diameter is used. The ball-mill discharge is returned to the first Akins classifier for additional classifying, screening, and concentration.

SLIME TREATMENT

The Dorr thickener at the head of the slime section is 20 feet in diameter and 8 feet high. Lime is added to the thickener at the rate of about 35 pounds per shift to aid in settling the solids. The underflow from the Dorr thickener is fed by a 3-way distributor to three Deister-Overstrom slime tables which produce concentrates and tailings. The tailings are sent to an 8 by 12 foot dewatering cone, the underflow of which is sent to three additional Deister-Overstrom slime tables. From the latter tables the tailings are distributed to three 4 by 18 foot canvas tables arranged in parallel. The slope of these tables is adjustable and varies from ½ to 2 inches per foot according to the pulp density of the feed handled. The canvas tables are used as pilot machines rather than as an adjunct to the other concentrating equipment. By visual inspection of the tables the mill operator can tell whether or not the maximum recovery of ferberite is being made. If more than the usual amount of slimed ferberite slows on the tables of the "rag plant," the mill equipment is adjusted to make a higher recovery.

The tailings from the three slime tables are conveyed by launder to a pond where they are impounded for possible future treatment. The tailings pond occupies a flat area of several acres near the mill. The sides of the pond have been built up by hand with earth retaining walls 4 to 6 feet high. The average WO_3 content of the tailings in the pond is about 1 per cent.

DRYING AND SACKING OF CONCENTRATES

The jig concentrates after draining in pans are dried in a Sutton coal-fired foundry sand dryer. The table concentrates because of their fineness are dryed in pans placed on top of an ordinary cookstove.

After drying, the two classes of concentrates are sacked separately for shipment in canvas sacks holding about 120 pounds each.

SAMPLING AND ASSAYING

The ores are sampled at the mill, as previously described, by a Vezin sampler. Custom ores usually are purchased in small lots, averaging less than 200 pounds each. The samples obtained by the Vezin sampler are crushed in a

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small cone crusher and divided by a Jones splitter until a final sample of about 1 pound is obtained. Each sample of pulp is divided into two parts, one of which is sent to the custom assayer at Boulder and the other kept at the mill until a satisfactory settlement is made with the seller. The cost of a tungsten trioxide (WO_3) determination by the Boulder assayer is $2.50.

The method used in determining the WO_3 content of ferberite ores and concentrates by the custom assayer at Boulder is essentially the same method given by Ledoux and Co.[6] In this method the ground sample is digested in HCl and HNO_3 and evaporated to dryness. The tungstic acid is then dissolved with NH_4OH and filtered. The filtrate is evaporated to dryness and weighed as WO_3.

For a number of years prior to 1927 the Wolf Tongue Co. employed a specific-gravity method for determining approximately the tungsten in ores and concentrates. This method was used for the control of mill operations and for furnishing an estimate of the value of custom ores, so that a partial settlement could be made on such ores on the same day as received. Final settlement on all ores purchased has always been made on custom assays.

The equipment necessary and the mode of operation for the specific-gravity method has been described by Hess as follows:[7]

> The articles needed are a flask holding about 1,500 cubic centimeters of water, and scales weighing in grams up to 3 or 4 kilos. The flask is counterbalanced, then 1,500 grams of water is weighed into it and the height marked on the neck.
>
> For determinations, 1,300 grams of water is weighed into the flask and the dry ore poured into the flask until the water is carried to the 1,500-gram (c.c.) mark. This means, of course, that the ore occupies 200 cubic centimeters and that an equal bulk of water weighs 200 grams. The weight of the water in the flask, 1,300 grams, is subtracted from the total weight, and the difference, which is the weight of the ore, is divided by 200 grams, the weight of the water displaced, thus giving the specific gravity, which is compared with a table (Table 1) giving the equivalent percentage of WO_3.

The figures given in Table 1 are based on the assumption that the gangue minerals are of fairly uniform specific gravity.

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6 Ledoux and Co.: South Dakota School of Mines, Bull. 12, p. 151, 1918.

7 Hess, Frank L., Tungsten Minerals and Deposits: U. S. Geol. Survey Bull. 652, 1917, pp. 71-72.

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Table 1.- Per cent of WO_3 indicated by specific gravity of Boulder district ferberite ores

Specific gravity for given percentages of WO_3 in ore	Percentage of WO_3 in ore	Specific gravity for given percentages of WO_3 in ore	Percentage of WO_3 in ore	Specific gravity for given percentages of WO_3 in ore	Percentage of WO_3 in ore
2.724	1	3.362	23	4.383	45
2.748	2	3.396	24	4.448	46
2.772	3	3.432	25	4.513	47
2.796	4	3.471	26	4.578	48
2.821	5	3.510	27	4.643	49
2.847	6	3.549	28	4.709	50
2.873	7	3.588	29	4.783	51
2.899	8	3.629	30	4.858	52
2.925	9	3.673	31	4.933	53
2.951	10	3.717	32	5.008	54
2.979	11	3.761	33	5.088	55
3.007	12	3.805	34	5.177	56
3.036	13	3.850	35	5.266	57
3.063	14	3.899	36	5.355	58
3.096	15	3.948	37	5.444	59
3.129	16	3.997	38	5.553	60
3.162	17	4.046	39	5.639	61
3.195	18	4.094	40	5.745	62
3.228	19	4.155	41	5.851	63
3.263	20	4.211	42	5.957	64
3.296	21	4.267	43	6.060	65
3.329	22	4.323	44		

CONCENTRATOR RECOVERY

The average recovery of WO_3 in 1931, as previously indicated, was 86.6 per cent; 16.3 per cent of the total WO_3 in the mill feed was recovered as low-grade concentrates containing an average of 31.73 per cent of WO_3; and the remainder, 70.3 per cent, was produced as high-grade concentrates containing 54.33 per cent of WO_3. Partial analyses of these two classes of concentrates as determined from previous shipments are about as follows:

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	High-grade concentrate, per cent	Low-grade concentrate, per cent
Tungsten trioxide ...	55.00	32.50
Phosphorus	0.035	0.07
Sulphur	0.06	0.30
Arsenic	0.025	0.01
Iron	22.50	11.00
Aluminum oxide	0.90	1.75
Silicon oxide	18.50	48.00
Manganous oxide	0.56	0.65
Molybdenum	Nil	Nil

Of the total recovery of 86.6 per cent of WO_3, 73.0 per cent was made by the jigs, and the remainder, 13.6 per cent, was made by the tables. The table concentrates are very fine, ranging from 100 to finer than 400 mesh.

The mill balance sheet for 1931 operations at the Wolf Tongue concentrator is given in Table 2.

Table 2.- Mill balance sheet, Wolf Tongue concentrator, 1931

	Weight of product, pounds	Assay, per cent WO_3	Contained WO_3, pounds	Contained WO_3, short-ton units	Percentage of total WO_3
Mill heads	2,499,970	5.72	142,998	7,149.9	100
Recovered by jigs:					
High-grade concentrates	156,286	53.16	83,082	4,154.1	58.1
Low-grade do.	67,844	31.41	21,307	1,065.4	14.9
Recovered by tables:					
High-grade concentrates	28,589	61.02	17,445	872.2	12.2
Low-grade do.	5,924	33.79	2,002	100.1	1.4
Tailings	2,241,327	0.855	19,162	958.1	13.4
Totals	2,499,970	-	142,998	7,149.9	100.0

EXPERIMENTAL WORK ON FLOTATION METHODS

Experimental work on the flotation treatment of Boulder district ferberite ores was done as early as 1916. Although flotation equipment has been installed in one mill of the district, this method of concentration has not been generally adopted. The objections to the use of the flotation process have been, in all probability, due to the fact that the ores varied considerably in WO_3 content and to the difficulty in keeping the percentage of phosphorus in the concentrate within the limit demanded by the consumers.

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Recent experimental work by Coghill and Clemmer indicates that flotation may prove applicable to the concentration of the ores, either as the principal method or as an adjunct to gravity concentration in the treatment of the slimes.

The results of the flotation experiments on Boulder district ferberite ore and mill slime as given by Coghill and Clemmer[8] are as follows:

> Two samples of Colorado ferberite were examined, a massive ore and a mill slime. In the first sample the mineral was so finely disseminated in quartz gangue that crushing to 200 mesh was required. The results of flotation are given in Table 3. The rougher concentrate was cleaned three times and the cleaner tailing is shown as "composite cleaner tailing." Whereas alkali is required for good roughing flotation, an excess destroys flotation. In the cleaning the usual practice was departed from by using sulphuric acid. This anomalous practice can be justified only by results. Sulphuric acid dispersed the remaining gangue and gave a concentrate of better grade. A slight excess destroyed flotation; the right amount gave a pulp just slightly acid. When acid is used in the cleaning, some additional pine oil may be required. The technique of repeated cleaning in the laboratory is difficult because the charge is so small. A larger amount of crude ore would have to be used for better results.

Table 3.- Colorado ferberite ore

Product	Weight, per cent	Assay, per cent WO_3	Percentage of total WO_3
Cleaner concentrate	13.7	50.00	77.4
Composite cleaner tailing	33.6	5.59	18.9
Rougher concentrate	47.3	20.28	96.3
Rougher tailing	52.7	0.69	3.7
Composite (feed)	100.0	9.91	100.0

Reagents used	Pounds per ton of crude ore			
	Rougher	Cleaner No. 1	Cleaner No. 2	Cleaner No. 3
Pine oil	0.08	-	-	0.04
Oleic acid	.24	-	-	-
Sodium oleate	.60	-	-	-
Sodium hydroxide	.75	-	-	-
Sodium silicate	-	0.20	-	-
Sulphuric acid	-	-	0.16	0.16

8 Coghill, Will H., and Clemmer, J. Bruce, Soap Flotation of the Non-sulphides: Tech. Pub. No. 445, Am. Inst. Min. and Met. Eng., 1932, pp. 14-15.

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The second sample was a mill slime, the screen analysis of which is shown in Table 4. The mineral was excessively fine and the sample was weathered. The gangue was quartz with some altered feldspars. The flotation results are given in Table 5, and show a very small loss in the rougher tailing, but the recovery in the cleaning operation was not good; the four cleanings left too much mineral in the middling. Doubtless plant operation would improve the technique enough to add to the recovery. The phosphorus content of the concentrate was not determined.

Table 4.- Screen analysis of Colorado ferberite mill slime

Size	Weight, per cent	Assay, per cent WO_3	Percentage of total WO_3
Plus 100 mesh	3.2	1.33	0.5
100 to 200 mesh	15.1	1.61	3.5
200 to 400 mesh	25.1	2.06	7.5
Minus 400 mesh	56.6	21.55	88.5
Composite (feed)	100.0	13.00	100.0

Table 5.- Colorado ferberite mill slime

Product	Weight, per cent	Assay, per cent WO_3	Percentage of total WO_3
Cleaner concentrate	11.8	49.90	46.2
Composite cleaner tailing	45.3	14.31	50.9
Rougher concentrate	57.1	21.66	97.1
Rougher tailing	42.9	0.87	2.9
Composite (feed)	100.0	12.74	100.0

Reagents used	Pounds per ton crude ore				
		Cleaner			
	Rougher	No. 1	No. 2	No. 3	No. 4
Pine oil	0.08	-	-	-	0.04
Oleic acid	.24	-	-	-	-
Sodium oleate	.60	-	-	-	-
Sodium hydroxide	.30	0.20	-	-	-
Sodium silicate	-	.20	-	-	-
Sulphuric acid	-	-	0.08	0.16	.16

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METALLURGICAL DATA AND MILLING COSTS

Metallurgical data for eight months of 1931 are presented in Table 6.

Table 6.- Metallurgical data, eight months of 1931

Total ore treated	dry tons	1,250
Company ore	do.	1,125
Lease ore	do.	125
Average WO_3 content in mill feed	per cent	5.72
Operating time, total	days	225
Operating time per day	hours	8
Average ore treated per eight hours	tons	5,556
Total concentrate produced	do.	129.321
Total high-grade concentrate	do.	92.437
Total low-grade concentrate	do.	36.884
Total recovery of WO_3	per cent	86.6
In high-grade concentrate	do.	70.3
In low-grade concentrate	do.	16.3
Ratio of concentration	tons into 1	9.7
WO_3 produced per ton of milled ore, average	pounds	99
Water consumption per ton of ore treated, net	tons (estimated)	6

When the mill operates on a one-shift basis a crew of three men is required, including the superintendent. The costs for treating 1,250 tons of ore containing 5.72 per cent of WO_3 for an 8-month period in 1931 are given in Table 7. In Table 8 a summary of the costs in units of labor, power, and supplies is given for the same period.

Table 7.- Summary of costs for eight months of 1931

	Labor	Power	Supplies and repairs	Total
Breaking, crushing, and grinding	$0.260	-	$0.168	$0.428
Screening and conveying	.519	-	.111	.630
Jigging	.779	-	.024	.803
Tabling	.519	-	-	.519
Assaying, sampling	1/ 3.300	-	-	3.300
Miscellaneous	-	$0.096	2/ .239	.335
Total	5.377	0.096	0.542	6.015

1/ Includes custom assaying charges. Custom assaying charges on 125 tons of lease ore averaged $28 per ton in 1931, or $2.80 per ton based on total tonnage treated. This high cost is due to the purchase of many small lots ore ore which averaged less than 200 pounds each.

2/ Includes drying and sacking of concentrates.

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Table 8.- Summary of costs in units of labor, power, and supplies

A - Labor (tons per 8-hour man-shift):	
Breaking, crushing, and grinding	16.7
Screening and conveying	8.4
Jigging	5.5
Tabling	16.7
Sampling	8.4
Tons per 8-hour man-shift, total labor	1.85
B - Power (kw.hr. per ton of ore treated):	
Breaking	3.3
Crushing	5.3
Grinding	5.4
Conveying and screening	4.3
Jigging	2.7
Tabling	5.7
Total	26.7
C - Labor, percentage of total direct cost	38.8
Power and supplies, percentage of total direct cost	10.7
Assaying, percentage of total direct cost	50.5

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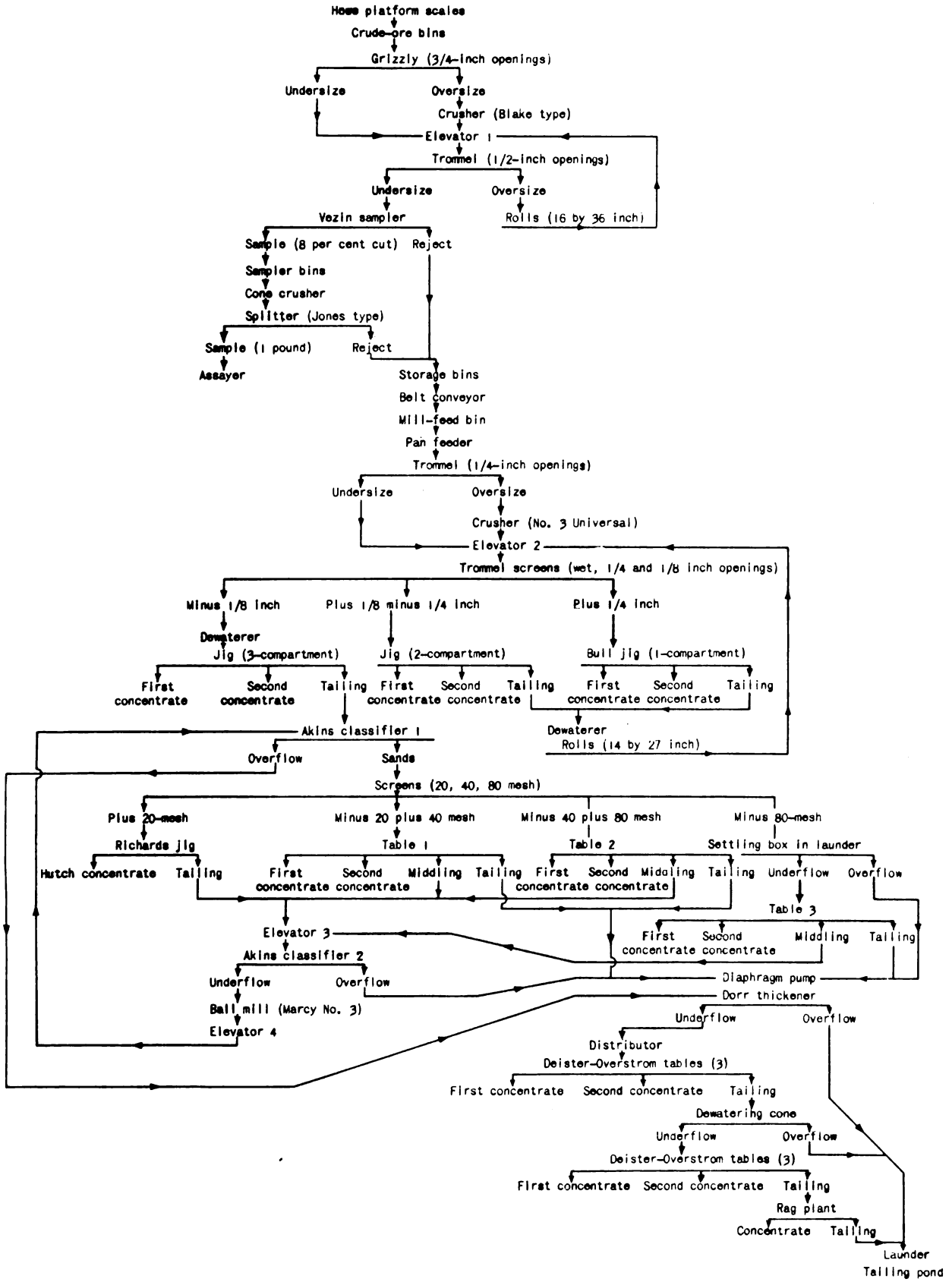

Figure 3.- Wolf Tongue concentrator flow sheet, 1932

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